[David Warner, W7SZS, photo]

RF Current Sensor

You can leave this sensor in-line to monitor the transmitter output.

David Warner, W7SZS

I recently became interested in using an RF ammeter to measure the RF current flowing into the feed point of an antenna. In articles that I read, there was not a lot of detailed guidance on how it could be used and what an acceptable reading might be. The objective of this article is to present the construction, calibration, and use of the RF current sensor. The sensor shown in the lead photo, and in Figure 1, is an alternative to more expensive RF test equipment.

Throughout this article, I use one specific scenario based on a similar actual measurement to provide guidance in understanding the measurements, and to demonstrate how the sensor can be used. This RF current sensor makes use of a digital multimeter (DMM) and a handful of inexpensive, readily available parts.

The Design

I found and studied several RF ammeter designs. Each design used either a powdered iron or ferrite toroid for the current transformer. Most of the designs used a primary-to-secondary turn ratio of either 1:10 or 1:20. The load resistor attached to the secondary ranged from 25 Ω to 10 kΩ. The sensing diode choices included the germanium 1N34A, silicon switching 1N914, and a Schottky-type 1N5711 device.

I selected a FT37-43 ferrite toroid for the current transformer with a single turn primary and 20 turns of #24 AWG enameled wire for the secondary winding. A 100 Ω load resistor was shunted across the secondary coil. I used an available new old-stock germanium diode for the peak voltage detector. Figure 2 shows a schematic for the RF current sensor.

Construction

Prepare a 3-inch piece of RG-58 solid-core coaxial cable by removing ap-

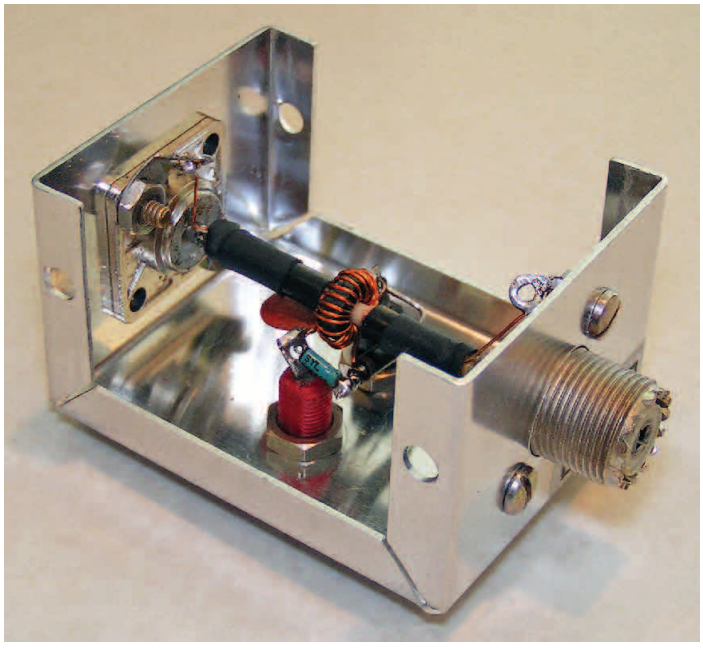

Figure 1 — RF current sensor components inside the shielded box.
[David Warner, W7SZS, photo]

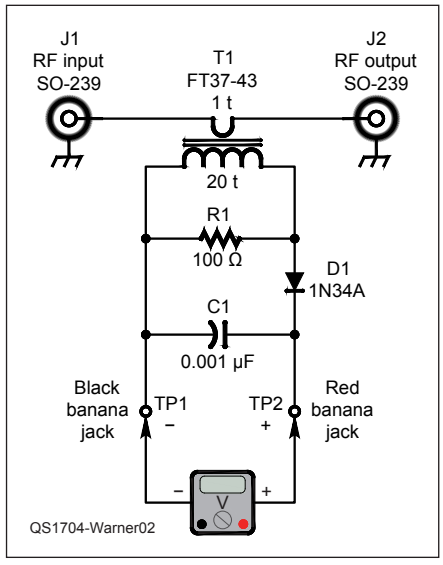

Figure 2 — Schematic diagram of the RF current sensor.
C1 — Capacitor, 0.001 µF
D1 — 1N34A germanium diode
J1, J2 — SO-239 chassis mount connector
R1 — Resistor, 100 Ω
T1 — 20 turns #24 AWG enameled wire wound on FT37-43 core
TP1 — Black banana jack
TP2 — Red banana jack

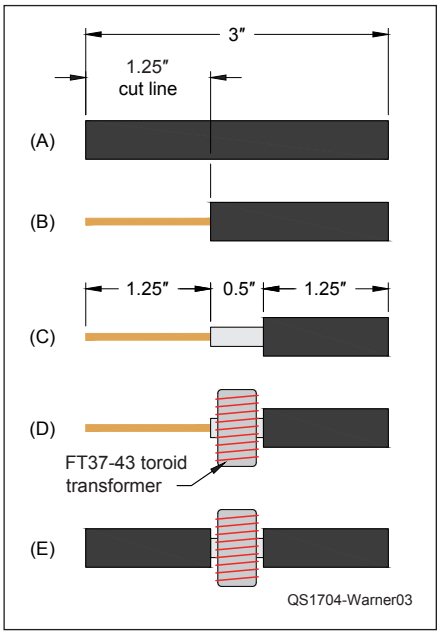

Figure 3 — Follow this sequence to insert the ferrite transformer into the transmission line.

proximately ½ inch of sheath and shielding from the middle of the rough-cut coax, leaving the center conductor insulation visible. The trick to preparing the coax is to use a tubing cutter to cut through the sheath, shield, and center conductor insulation.

Figure 3 illustrates the construction sequence. In (A), I made the initial cut 1¼ inches from one end of the coaxial cable, allowing the short end layers of the cable to be pulled off the center conductor intact as a single assembly (B) for reuse later. I then stripped the sheath and braided shield (C) off the other side of the cut for ½ inch, leaving the center conductor insulation exposed. The FT37-43 toroid transformer with its winding is then slipped on (D), with a tight fit to the center conductor. This becomes the single-turn primary of the transformer. The previously removed piece of shield and center insulation is then (E) slipped back onto the center conductor and butted up against the original cut.

This RF current sensor makes use of a digital multimeter (DMM) and a handful of inexpensive, readily available parts.

I trimmed the ends of the RG-58 coax to fit into the SO-239 center pin solder cups, and groomed the shield at each end using the "Neat Coaxial Shield Connections" hint.[1] I slipped heat-shrink tubing over the connections for a clean appearance.

I selected banana jacks for connecting the DMM to the sensor. A pair of 18-inch lengths of black and red flexible test leads, terminated with banana plugs on each end, allows for a direct connection of the DMM to the sensor.

I used point-to-point wiring for the component connections, keeping all leads as short as possible. My sensor is housed inside a Bud CU-3000-A 2.75 × 2.12 × 1.62 inch aluminum Minibox.

Testing, Calibration, and Operation

Testing and calibration are straightforward, especially if you have access to an in-line RF power meter and a known 50 Ω purely resistive dummy load with a rating of at least 100 W.

Connect the output of the transmitter to the RF in-line power meter, and the output of the power meter to one side of the RF current sensor. Connect the other side of the RF current sensor to the dummy load.

Connect the DMM to the current sensor banana jacks, observing polarity, and set it to read dc volts. Key the transmitter in CW mode on an HF band of your choice, and adjust the transmitter output for 50 W. Ideally, there should be less than 0.1 W of reflected power when operating into the 50 Ω dummy load. Note the voltage reading on the DMM. Switch to another band without making any changes, and observe the DMM voltage and RF power readings. There should be minimal deviation in the readings across the bands tested.

The rms amperes of RF current flow into the dummy load and on the primary of the current sensor is

$$I_{PRI} = \frac{(V_{PEAK} + V_{DIODE})}{T_{RATIO} R_{LOAD} \sqrt{2}} \qquad \text{[Eq. 1]}$$

where the square root of 2 is the peak-to-rms ratio, and

V_{PEAK} is the measured peak dc voltage from the current sensor,

V_{DIODE} is the voltage drop across the diode (about 0.5 V dc),

R_{LOAD} is the load resistance terminating the transformer secondary,

T_{RATIO} is the transformer primary to secondary turns ratio.

In a test scenario, 50 W is applied to the 50 Ω dummy load. We measure 6.6 V dc across R_{LOAD}, the 100 Ω secondary load resistor. The diode is a germanium type with an approximate voltage drop V_{DIODE} of 0.5 V. The diode voltage drop will increase nonlinearly as the input voltage increases. The transformer has a one-turn primary and 20-turn secondary, so the turns ratio T_{RATIO} is 1/20 = 0.05. Therefore, the rms RF current in the primary is

$$(6.60 + 0.5) \Big/ (0.05 \cdot 100 \cdot \sqrt{2}) = 1.004 \text{ A}$$

We can verify the result with the following relationship between current and power:

$$I = \sqrt{\frac{P}{R}} \qquad \text{[Eq. 2]}$$

where I is the rms RF current flowing into the dummy load resistance R, and P is the RF power in watts. We see that

$$\sqrt{\frac{50 \text{ W}}{50 \Omega}} = 1.0 \text{ A}$$

When an RF power meter is not available, we can invert Eq. 2 to determine the input power to the 50 Ω dummy load given the result from Eq. 1,

$$P = I^2 R \qquad \text{[Eq. 3]}$$

and calculate

$(1.004\ \text{A})^2(50\ \Omega) = 50\ \text{W}$

Now with the current sensor calibrated to a selected power output level, the sensor can be placed in the transmission line between the transmitter and the antenna feed point to obtain an RF current measurement. A DMM with the MIN/MAX feature enabled makes it easy to capture the measurement. The maximum (calibrated) RF current measurement divided by the RF current measured at the feed point is the RF current ratio of the antenna feed point relative to the dummy load.

Continuing with our 50 W test scenario, let's say that we've measured 0.926 A (6.05 V dc) *at the antenna feed point*. Therefore, the ratio is 1.00 A/0.926 A = 1.08.

That ratio is equivalent to the standing-wave ratio (SWR). Remember that the SWR is the ratio of *voltage maximum* to *voltage minimum* on a transmission line, but it also equals the ratio of the *current maximum* to the *current minimum* on the transmission line. Always divide the maximum value by the minimum value, because by convention, SWR is always one or greater.

Some Uses for the RF Current Sensor

The RF current sensor can be placed in the transmission line between the transmitter or the output of an antenna tuner and the antenna to continually monitor antenna performance without tying up more expensive equipment. It can also be used to determine the resistive part of an antenna feed-point impedance.

An antenna feed-point resistance rela-

What Current and Power Sensors Measure

Forward and reflected waves create an interference standing-wave pattern on a transmission line, which are sensed differently by different instruments.

Figure A shows the standing-wave current (blue) and voltage (red) illustrated on a lossless transmission line resulting from a load impedance that is different from the characteristic impedance — typically 50 Ω, but normalized to 1 Ω in Figure A — of the transmission line.

The RF current sensor measures I_{TOTAL}, the magnitude of the *sum* of the forward and reflected currents on a transmission line, $I_{TOTAL} = I_{FORWARD} + I_{REFELCTED}$, in Figure A at the point where the RF current sensor is inserted in the transmission line. If it were physically possible to gradually move that RF current sensor to find and measure the peak current, I_{PEAK}, then move and search for the minimum current, $I_{MINUMUM}$, we could calculate the *SWR* directly as

$$SWR = \frac{I_{PEAK}}{I_{MINIMUM}}\text{, which also equals } \frac{V_{PEAK}}{V_{MINIMUM}}$$

in Figure A, and is the definition of *SWR*. Furthermore, the forward and reflected currents, along with the distance between the load and the first current minimum can be used to determine the complex impedance of the load.

An in-line "power meter" is actually a *directional* RF signal meter that displays a diode-rectified meter current limited by a meter resistance.

$$I_{METER} = \left(V_{FORWARD} + V_{DIODE}\right)/\left(R_{METER}\right)$$

and can be set to measure the magnitude of either the forward travelling signal, $V_{FORWARD}$, or the signal reflected from the load, $V_{REFLECTED}$. The forward and reflected voltages and currents are *constant* everywhere in a lossless transmission line, so unlike the RF current sensor, you get the same answer no matter where along the transmission line you insert the in-line RF power meter.

The in-line RF power meter scale is linear in detected current, I_{METER}, to within the sensor diode voltage drop, V_{DIODE}, but its meter face scale is drawn distorted, or "calibrated," to display $P_{FORWARD}$ or $P_{REFLECTED}$ using $P = KI^2_{METER}$, where K is a scaling constant. The face of this same directional signal meter can also be distorted (or "calibrated") to display

$$SWR = \frac{\sqrt{P_{FORWARD}} + \sqrt{P_{REFLECTED}}}{\sqrt{P_{FORWARD}} - \sqrt{P_{REFLECTED}}}$$

as commonly seen in the ham shack. — *Ed.*

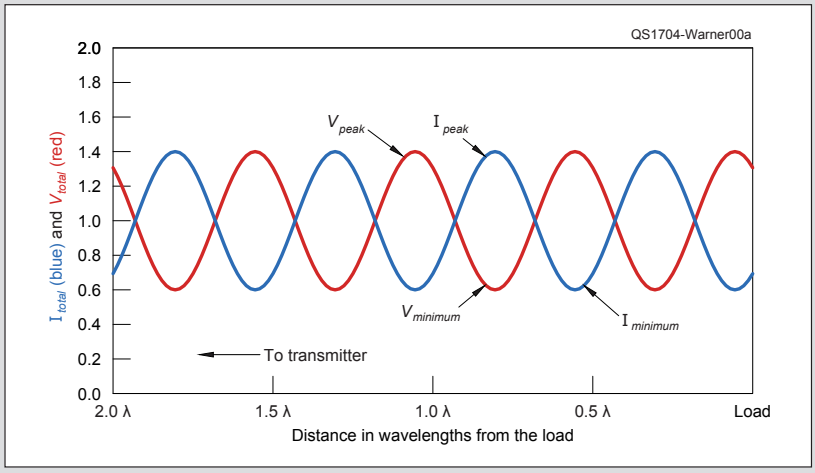

Figure A — Voltage and current standing waves on a transmission line terminated in a complex impedance that results in a 1.4/0.6 = 2.33 SWR.

tive to a 50 Ω dummy load can be approximated using the standing-wave ratio found in our 50 W test scenario. The resulting feed-point resistance is 50 Ω × 1.08 = 54 Ω.

Alternatively, one can use the standard voltage equation to obtain the source RF voltage when the power and resistance are known. The RF voltage can then be divided by the measured RF current. The rms voltage in terms of power, P, and dummy load resistance, R_{load}, is

$$V_{rms} = \sqrt{P \cdot R_{LOAD}} \qquad \text{[Eq. 4]}$$

so, $\sqrt{(50\text{ W})(50\ \Omega)} = 50$ volts rms. Therefore, the RF voltage divided by the measured RF current is the antenna feed-point resistance, (50 V)/(0.926 A) = 53.99 Ω.

You can also use the voltage measurements to determine that ratio. In our scenario, we measured 6.6 V dc when connected to the 50 Ω dummy load and 6.05 V dc when connected at the antenna feed point. That ratio is 1.09, so the calculated antenna feed-point resistance relative to the 50 Ω dummy load resistance is (50 Ω) (1.09) = 54.5 Ω compared with 53.99 Ω obtained from the prior method — a negligible 0.9% difference.

The trick to preparing the coax is to use a tubing cutter to cut through the sheath, shield, and center conductor insulation.

When the RF current sensor is placed in the transmission line between the transmitter or antenna tuner and the antenna feed point, the RF current can be monitored continuously if desired. The RF current measurement, along with a given RF voltage, can be used to calculate the power supplied to the antenna using the power formula

$$P = I_{rms} V_{rms} \qquad \text{[Eq. 5]}$$

Using our scenario source voltage of 50 V rms and the measured current of 0.926 A rms at the antenna feed point, we find that the 46.3 W RF power is supplied to the antenna. We find the same ratio, 1.08, again when dividing the source power, 50 W, by the calculated power, 46.3 W.

Recall that the ratio found and used in the above discussion is a comparison between the measurement into a reference dummy load and a measurement using the antenna system. It is not the same ratio as the antenna/transmission line system voltage maximum to voltage minimum or current maximum to current minimum ratio.

Summary

The RF current sensor provides us with a good indication of how our antenna system is performing. The sensor will show us that when the RF current is equal to, or slightly above or below, a reference current value — such as with a dummy load — the antenna system is presenting an equal or nearly equal impedance match to the RF source. Should the RF current at the antenna feed point be considerably lower than the reference current, then the antenna system is presenting a high impedance. And conversely, if the current is high, then the antenna system is presenting a low impedance.

The articles "Keeping Current with Antenna Performance" by KL7AJ[2] and "My Feedline Tunes My Antenna" by Byron Goodman, W1DX (SK)[3], along with technical correspondence from Steve Noskowicz, K9DCI[4], will provide you with additional insight on the theory and measurement of RF current.

[The sidebar, "What Current and Power Sensors Measure," explains what various RF sensors measure. — *Ed.*]

Notes

[1]D. DeMaw, W1CER (SK), "Neat Coaxial Shield Connections" (Hints and Kinks), *QST*, Apr. 1966, p. 66.

[2]E. P. Nichols, KL7AJ, "Keeping Current with Antenna Performance," *QST*, Feb. 2009, pp. 34 – 36.

[3]B. Goodman, W1DX (SK), "My Feedline Tunes My Antenna," *QST*, Mar. 1956, pp. 49 – 51, 124.

[4]S. Noskowicz, K9DCI, "Keeping Current with Antenna Performance" (Technical Correspondence), *QST*, Jul. 2010, pp. 50 – 51.

David Warner, W7SZS, was first licensed as KA71JK in 1980. The call sign W7SZS was previously held by his grandfather from 1954 to 1994. His grandfather introduced him to Amateur Radio in the mid-1960s, when David was about 7 years old. Since then, David has always been building something inspired by *QST* articles and ARRL publications. He is also active in ARES, packet radio, SSTV, and HF, VHF, and UHF communications. David is Vice President of Engineering and Information Technology at Beaver Creek Cooperative Telephone Company, where he has worked for more than 37 years. He applies the knowledge acquired through his involvement with Amateur Radio to his professional responsibilities. You can reach David at **w7szs@arrl.net**.

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